Department of Physics

$E = mc^2$

College of Science
UNIVERSITY OF KIRKUK

INTRODUCTION

Subject: Material Science - Lecture #1

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Physics Department – 3rd grade

HISTORICAL PERSPECTIVE

- Transportation, housing, clothing, communication, recreation, and food production virtually every segment of our everyday lives is influenced to one degree or another by materials.

Historically, early civilizations have been designated by the level of their materials development (Stone Age, Bronze Age, Iron Age).

- Stone Age (2.5 million BC) People began to make tools from stone, wood, clay, skins, and so on.

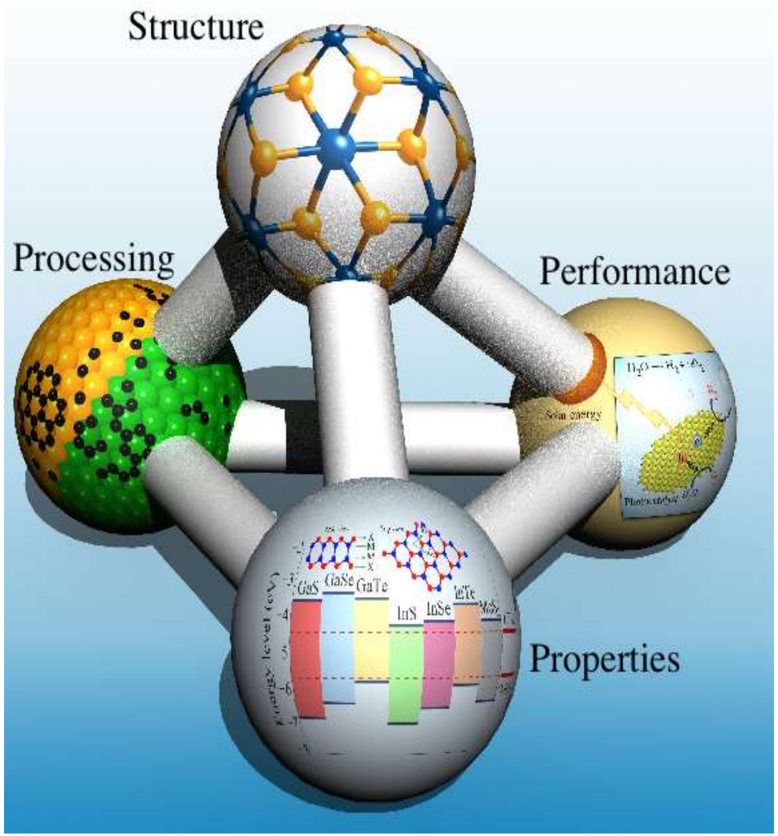
- Bronze Age (3500 BC) The Stone Age ended with introduction of Bronze in the Far East. Bronze is an alloy (a metal made up of more than one element), copper + < 25% of tin + other elements.
- Iron Age (1000 BC) Use of iron and steel, a stronger and cheaper material changed drastically daily life of a common person.
- Age of Advanced materials: throughout the Iron Age many new types of materials have been introduced (ceramic, semiconductors, polymers, composites…).

An advancement in the understanding of a material type is often the indication to the stepwise progression of a technology.

MATERIALS SCIENCE AND ENGINEERING

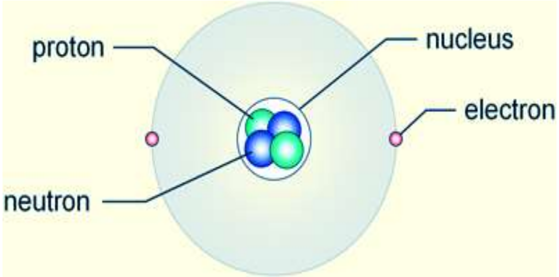
- Materials science involves investigating the relationships that exist between the structures and properties of materials.
- Materials engineering involves, on the basis of these structure–property correlations, designing or engineering the structure of a material to produce a predetermined set of properties.

Materials science

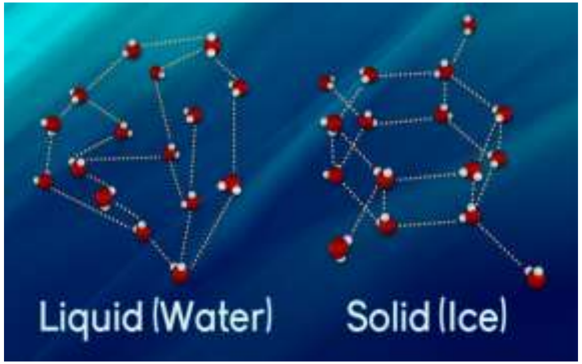


Structure

The structure of a material usually relates to the arrangement of its internal components.



Subatomic structure involves electrons within the individual atoms and interactions with their nuclei.

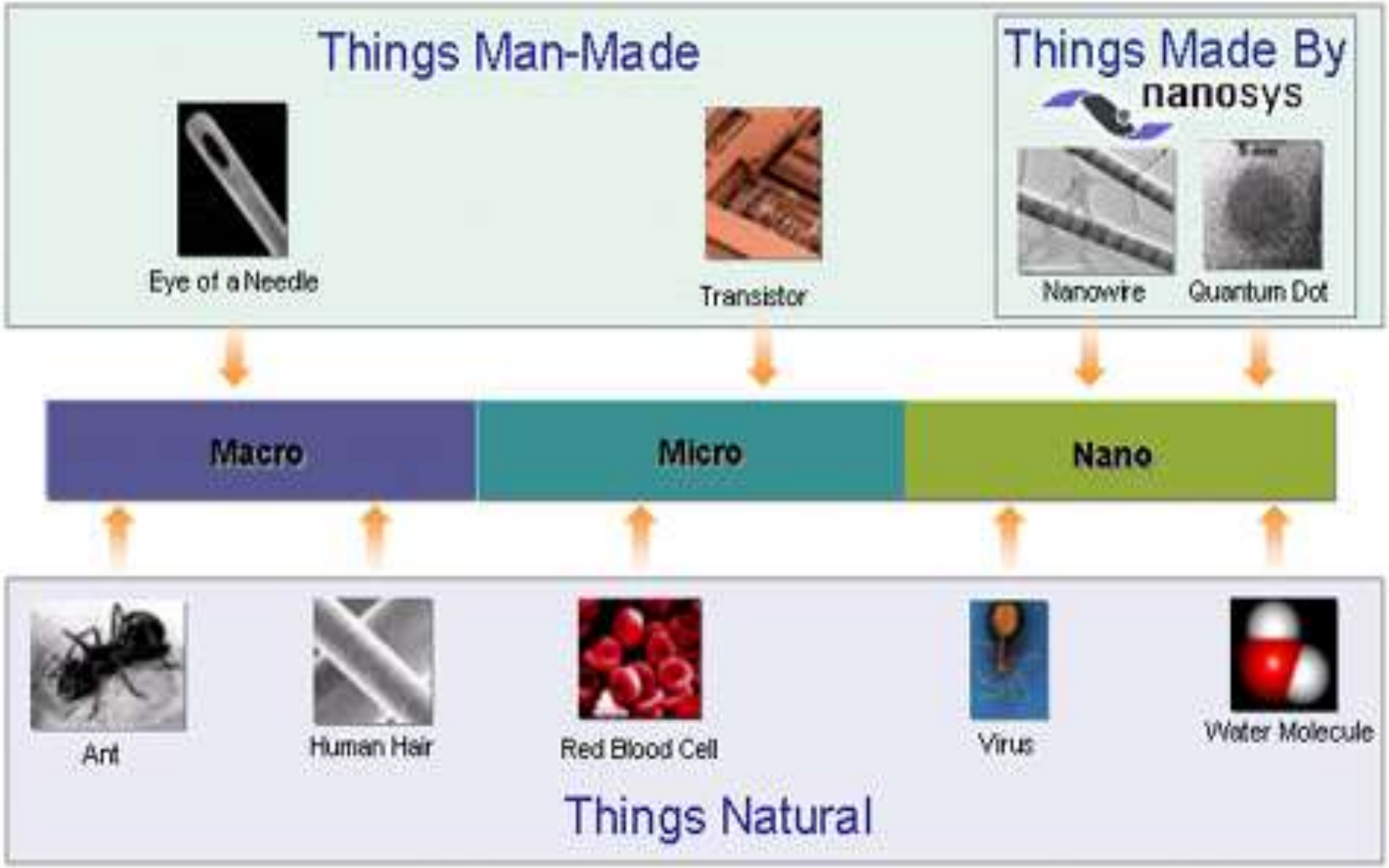


On an *atomic level*, structure involve the organization of atoms or molecules relative to one another.

__microscopic structure__, $(1\mu = 10^{-6}\ \text{m})$ which contains large groups of atoms that are normally agglomerated together, is termed microscopic, meaning that which is subject to direct observation using some type of microscope.

__macroscopic structure__, structural elements that can be viewed with the naked eye.

Whatman Filter Paper under SEM


Things Man-Made
Eye of a Needle
Transistor
Things Made By
nanosys
Nanowire
Quantum Dot
Macro
Micro
Nano
Ant
Human Hair
Red Blood Cell
Virus
Water Molecule
Things Natural

Property

All materials are exposed to external stimuli that induce some type of response.

All important properties of solid materials may be grouped into six different categories:

1) Mechanical properties relate deformation to an applied load or force; examples include elastic modulus (stiffness), strength, and toughness.
2) Electrical properties, such as electrical conductivity and dielectric constant, the stimulus is an electric field.

3) Thermal behavior of solids can be represented in terms of heat capacity and thermal conductivity.
4) Magnetic properties demonstrate the response of a material to the application of a magnetic field.
5) Optical properties, the stimulus is electromagnetic or light radiation; index of refraction and reflectivity are representative optical properties.
6) Deteriorative characteristics relate to the chemical reactivity of materials.

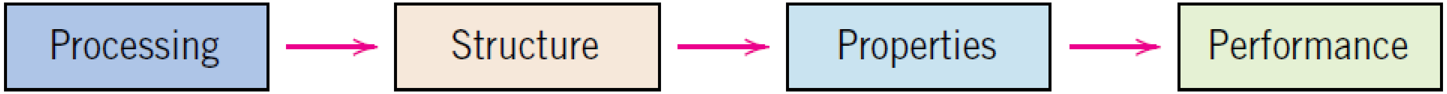
Processing

The structure of a material depends on how it is processed.

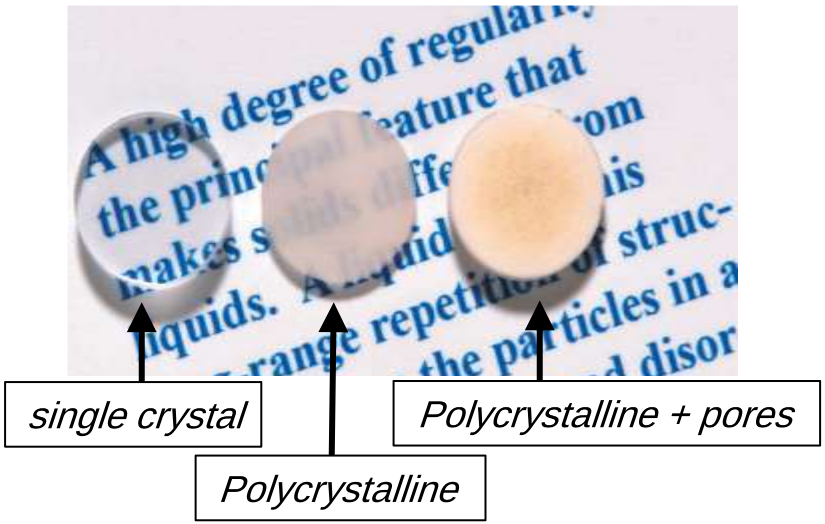
performance

A material's performance is a function of its properties.

The interrelationship among processing, structure, properties, and performance is as depicted in the schematic illustration shown in Figure below



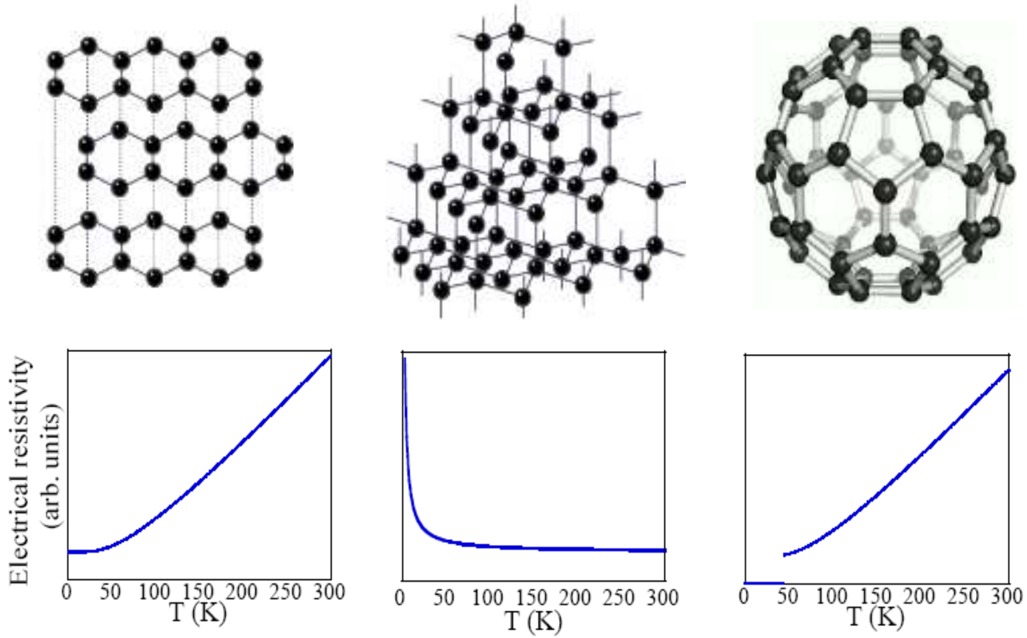
An example of these processing-structure-properties-performance principles in Figure below three thin disk specimens of aluminum oxide



These differences in optical properties are a consequence of differences in structure of these materials, which have resulted from the way the materials were processed.

An example of electrical resistivity of three states of solid matter they are all just carbon!

graphite diamond buckminsterfullerene



Metal Insulator Superconductor

WHY STUDY MATERIALS SCIENCE?

A materials problem is one of selecting the right material from the thousands available.
On only rare occasions does a material possess the maximum or ideal combination of properties.
Thus, it may be necessary to trade one characteristic for another.

Solar cell efficiency tables (version 50) 21 June 2017

Classification	Efficiency (%)	Area (cm^2)	V_{oc} (V)	J_{sc} (mA/cm^2)	Fill Factor (%)	Test Centre (date)	Description
Silicon							
Si (crystalline cell)	**26.7 ± 0.5**	**79.0 (da)**	**0.738**	**42.65[a]**	**84.9**	**AIST (3/17)**	**Kaneka, n-type rear IBC[5]**
Si (multicrystalline cell)	**21.9 ± 0.4[b]**	**4.0003 (t)**	**0.6726**	**40.76[a]**	**79.7**	**FhG-ISE (2/17)**	**FhG-ISE, n-type[6]**
Si (thin transfer submodule)	21.2 ± 0.4	239.7 (ap)	0.687[c]	38.50[c,d]	80.3	NREL (4/14)	Solexel (35 μm thick)[7]
Si (thin film minimodule)	10.5 ± 0.3	94.0 (ap)	0.492[c]	29.7[c]	72.1	FhG-ISE (8/07)[e]	CSG Solar (<2 μm on glass)[8]
III-V cells							
GaAs (thin film cell)	28.8 ± 0.9	0.9927 (ap)	1.122	29.68[f]	86.5	NREL (5/12)	Alta Devices[9]
GaAs (multicrystalline)	18.4 ± 0.5	4.011 (t)	0.994	23.2	79.7	NREL (11/95)	RTI, Ge substrate[10]
InP (crystalline cell)	**24.2 ± 0.5[b]**	**1.008 (ap)**	**0.939**	**31.15[a]**	**82.6**	**NREL (9/12)**	**NREL[11]**
Thin film chalcogenide							
CIGS (cell)	**21.7 ± 0.5**	**1.044 (da)**	**0.718**	**40.70[a]**	**74.3**	**AIST (1/17)**	**Solar Frontier[12]**
CdTe (cell)	21.0 ± 0.4	1.0623 (ap)	0.8759	30.25[d]	79.4	Newport (8/14)	First Solar, on glass[13]
CZTS (cell)	**10.0 ± 0.2**	**1.113 (da)**	**0.7083**	**21.77[a]**	**65.1**	**NREL (3/17)**	**UNSW[14]**
Amorphous/microcrystalline							
Si (amorphous cell)	10.2 ± 0.3[g,b]	1.001 (da)	0.896	16.36[d]	69.8	AIST (7/14)	AIST[15]
Si (microcrystalline cell)	**11.9 ± 0.3[b]**	**1.044 (da)**	**0.550**	**28.72[a]**	**75.0**	**AIST (2/17)**	**AIST[16]**
Perovskite							
Perovskite (cell)	19.7 ± 0.6[g,h]	0.9917 (da)	1.104	24.67[i]	72.3	Newport (3/16)	KRICT/UNIST[17]
Perovskite (minimodule)	**16.0 ± 0.4[g,h]**	**16.29 (ap)**	**1.029[c]**	**19.51[c,a]**	**76.1**	**Newport (4/17)**	**Microquanta, 6 serial cells[18]**
Dye sensitised							
Dye (cell)	11.9 ± 0.4[j]	1.005 (da)	0.744	22.47[k]	71.2	AIST (9/12)	Sharp[19]
Dye (minimodule)	10.7 ± 0.4[j]	26.55 (da)	0.754[c]	20.19[c,l]	69.9	AIST (2/15)	Sharp, 7 serial cells[19]
Dye (submodule)	8.8 ± 0.3[j]	398.8 (da)	0.697[c]	18.42[c,m]	68.7	AIST (9/12)	Sharp, 26 serial cells[20]
Organic							
Organic (cell)	11.2 ± 0.3[n]	0.992 (da)	0.780	19.30[d]	74.2	AIST (10/15)	Toshiba[21]
Organic (minimodule)	9.7 ± 0.3[n]	26.14 (da)	0.806	16.47[c,l]	73.2	AIST (2/15)	Toshiba (8 series cells)[22]

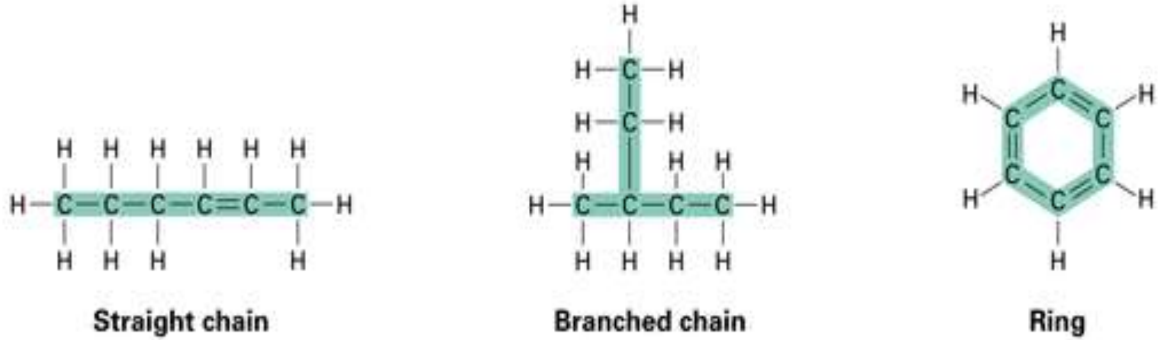
CLASSIFICATION OF MATERIALS

Solid materials have been grouped into three basic categories: metals, ceramics, and polymers, based primarily on chemical makeup and atomic structure.
In addition, there are the composites that are engineered combinations of two or more different materials.
Another category is advanced materials those used in high technology applications, such as semiconductors, biomaterials, smart materials, and nanoengineered materials

Metals are composed of one or more metallic elements (e.g., iron, aluminum, copper, titanium, gold, nickel), and often also nonmetallic elements (e.g., carbon, nitrogen, oxygen)

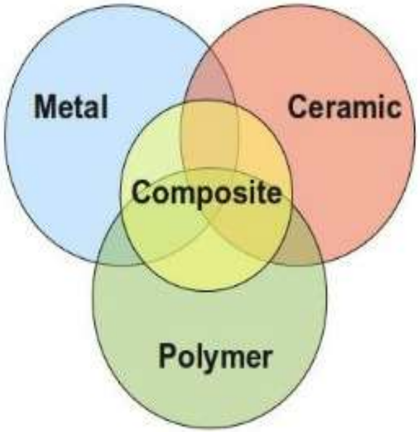
Ceramics are compounds between metallic and nonmetallic elements; they are most frequently oxides, nitrides, and carbides. For example, common ceramic materials include aluminum oxide (or alumina, Al_2O_3), silicon dioxide (or silica, SiO_2), silicon carbide (SiC), silicon nitride (Si_3N_4), and, in addition, what some refer to as the traditional ceramics those composed of clay minerals (e.g., porcelain), as well as cement and glass.

Polymers include the familiar plastic and rubber materials. Many of them are organic compounds that are chemically based on carbon, hydrogen, and other nonmetallic elements (i.e., O, N, and Si). Furthermore, they have very large molecular structures, often chainlike in nature, that often have a backbone of carbon atoms. Some common and familiar polymers are polyethylene (PE), nylon, poly(vinyl chloride) (PVC), polycarbonate (PC), polystyrene (PS), and silicone rubber.

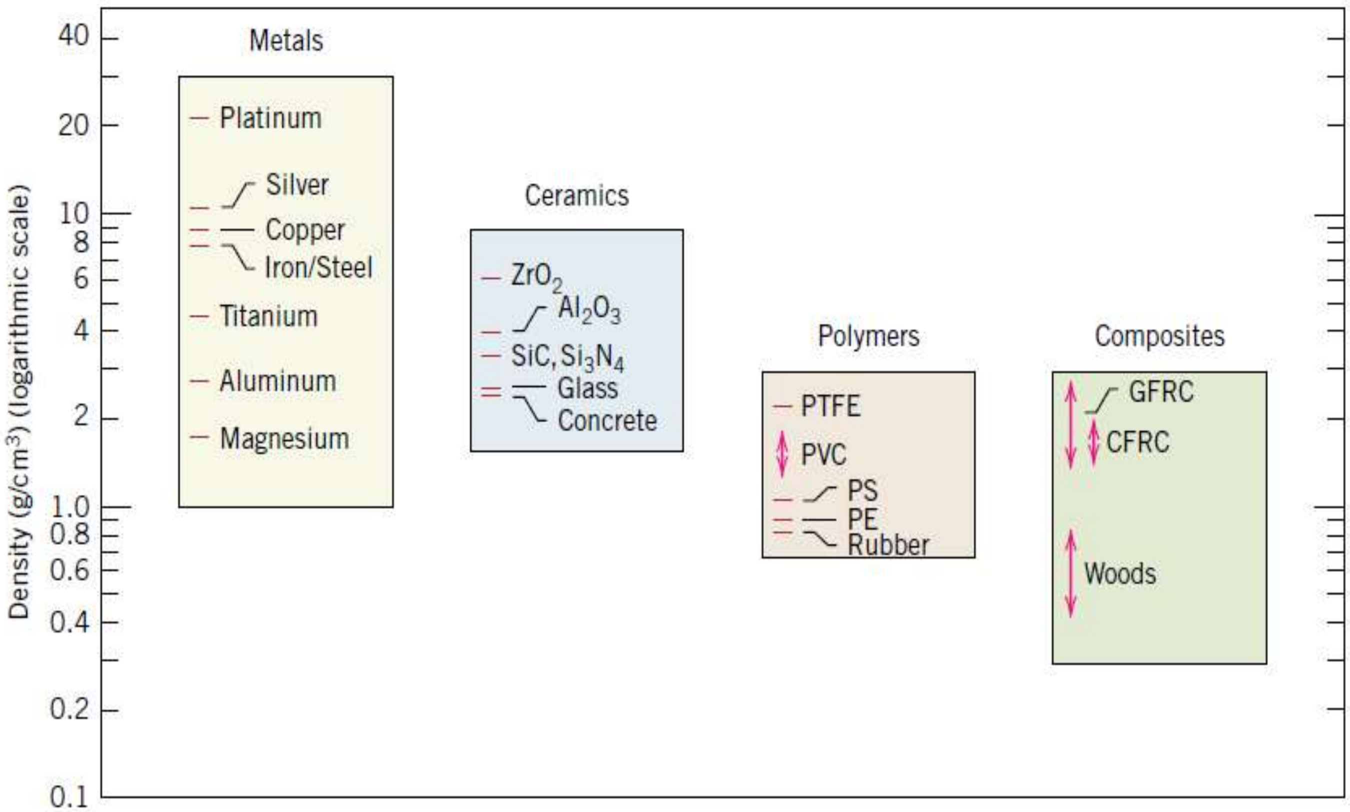


A composite is composed of two (or more) individual materials that come from the categories previously discussed metals, ceramics, and polymers.

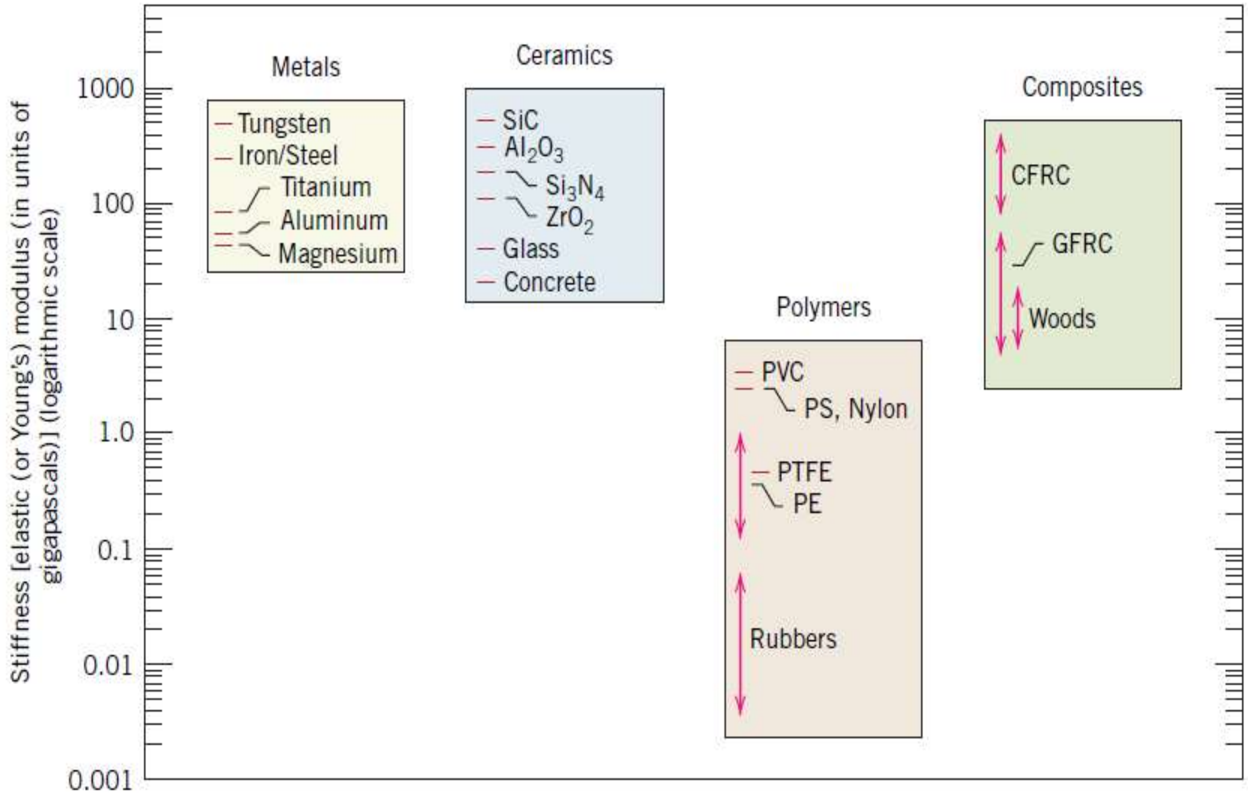
The design goal of a composite is to achieve a combination of properties that is not displayed by any single material and also to incorporate the best characteristics of each of the component materials.



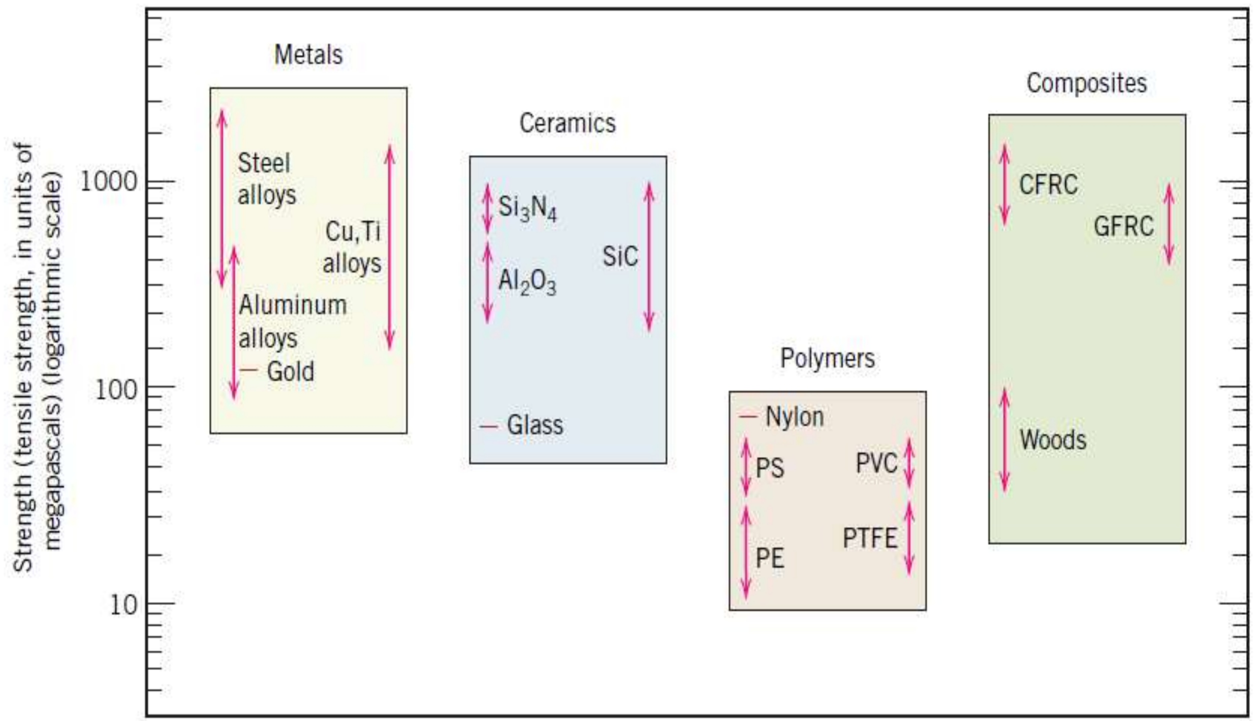
Some naturally occurring materials are composites for example, wood and bone.
One of the most common and familiar composites is fiberglass, in which small glass fibers are embedded within a polymeric material (normally an epoxy or polyester).



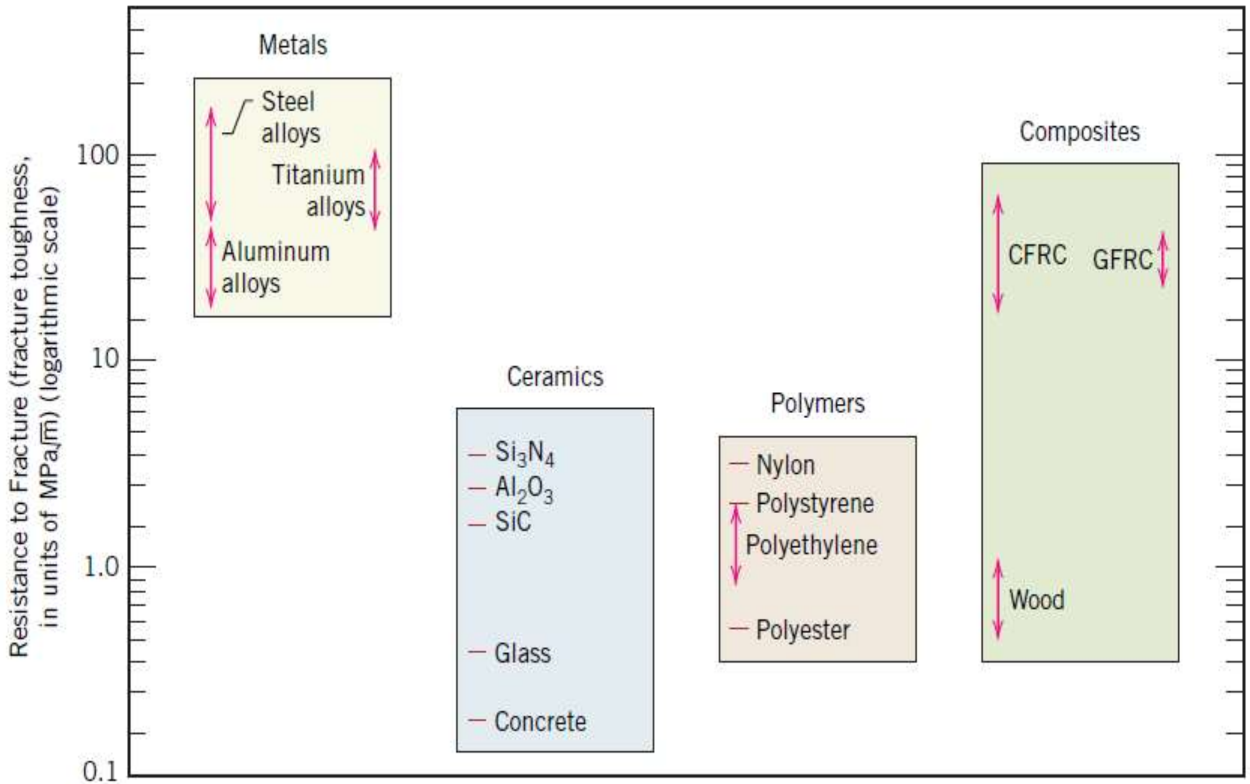
Bar chart of room temperature <u>density</u> values for various metals, ceramics, polymers, and composite materials.



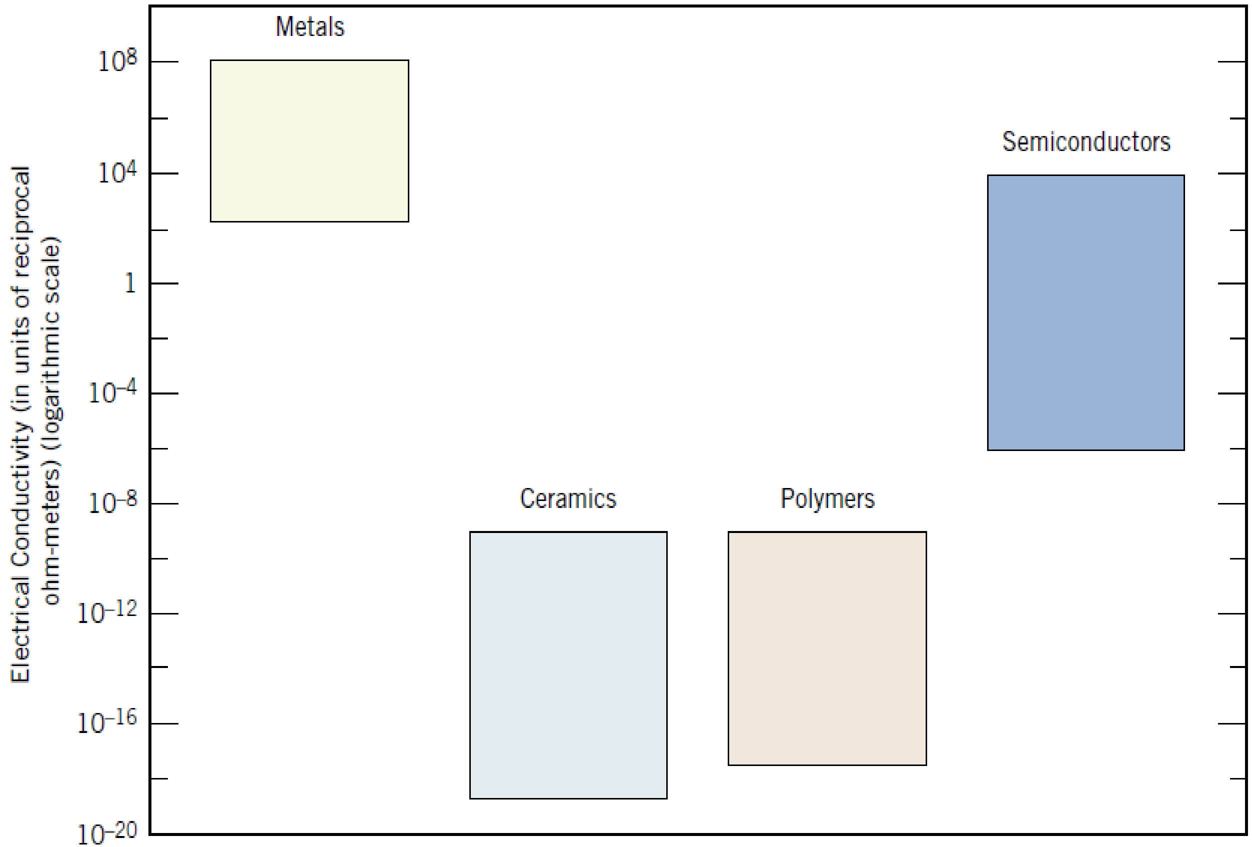
Bar chart of room temperature <u>stiffness</u> (i.e., elastic modulus) values for various metals, ceramics, polymers, and composite materials.



Bar chart of room temperature strength (i.e., tensile strength) values for various metals, ceramics, polymers, and composite materials.



Bar chart of room temperature <u>resistance to fracture</u> (i.e., fracture toughness) for various metals, ceramics polymers, and composite materials.



Bar chart of room temperature electrical conductivity ranges for metals, ceramics, polymers, and semiconducting materials.

ADVANCED MATERIALS

Materials utilized in high-technology (or high-tech) applications are sometimes termed *advanced materials* including electronic equipment (camcorders, CD/DVD players), computers, fiber-optic systems, spacecraft, aircraft, and military rocketry.

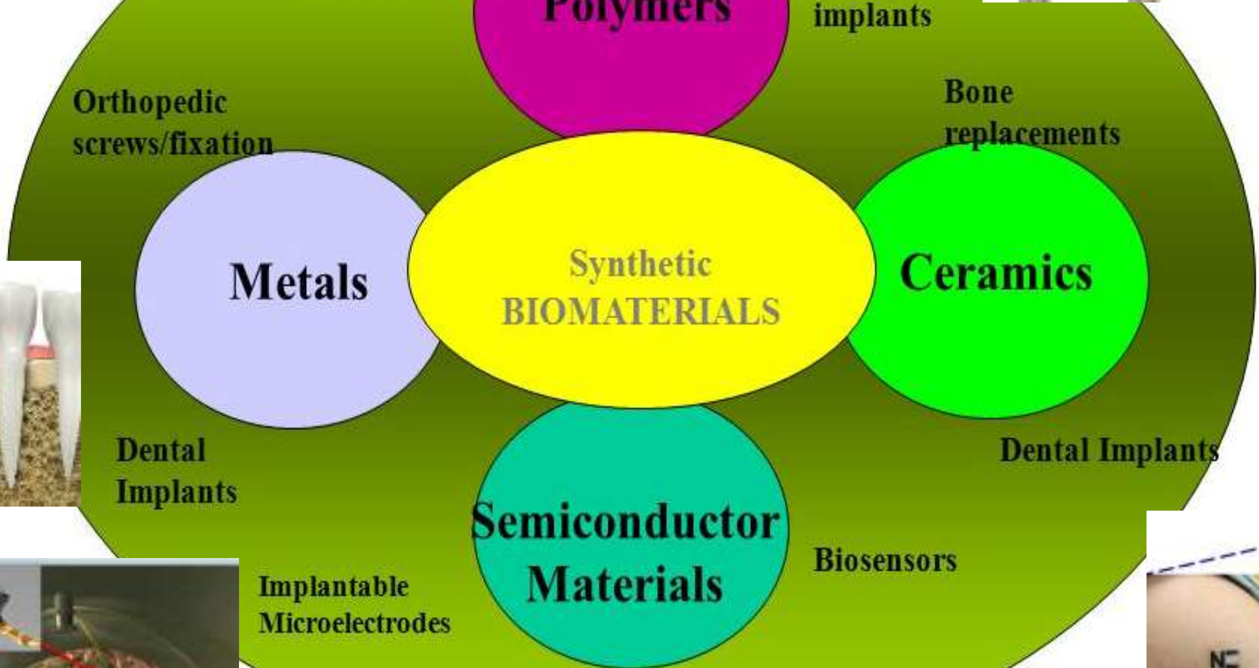
- These advanced materials are typically traditional materials whose properties have been enhanced and also newly developed, high-performance materials.
- they may be of all material types (e.g., metals, ceramics, polymers) and are normally expensive.
- Advanced materials include semiconductors, biomaterials, smart materials and nanoengineered materials

Semiconductors

- Have electrical properties that are intermediate between those of electrical conductors (i.e., metals and metal alloys) and insulators (i.e., ceramics and polymers)
- The electrical characteristics of these materials are extremely sensitive to the presence of minute concentrations of impurity atoms,
- Semiconductors have made possible the advent of integrated circuitry that has totally revolutionized the electronics and computer industries over the past three decades.

Biomaterials

- Biomaterials are employed in components implanted into the human body to replace diseased or damaged body parts.
- These materials must not produce toxic substances and must be compatible with body tissues (i.e., must not cause adverse biological reactions).
- All of the preceding materials such as metals, ceramics, polymers, composites, and semiconductors may be used as biomaterials.



The biosensor, applied to the human skin like a temporary tattoo, can alert marathoners, competitive bikers and other “hit the wall,”

Smart materials

- materials that are able to sense changes in their environment and then respond to these changes in predetermined manners traits that are also found in living organisms.
- smart material (or system) include some type of sensor (which detects an input signal) and an actuator (which performs a responsive and adaptive function).
- Actuators may be called upon to change shape, position, natural frequency, or mechanical characteristics in response to changes in temperature, electric fields, and/or magnetic fields.

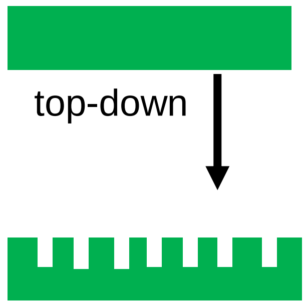
Four types of materials are commonly used for actuators:

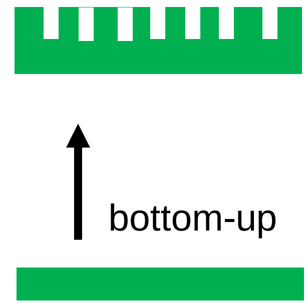
1. shape-memory alloys
2. piezoelectric ceramics
3. magnetostrictive materials
4. electrorheological/magnetorheological fluids

Nanomaterials

- material that has fascinating properties and tremendous technological promise.
- It may be any one of the four basic types such as metals, ceramics, polymers, or composites.
- However, unlike these other materials, they are not distinguished on the basis of their chemistry but rather their size.
- The nano prefix denotes that the dimensions of these structural entities are on the order of a nanometer ($10^{-9} m$) as a rule, less than 100 nanometers (nm; equivalent to the diameter of approximately 500 atoms).

- There are two approach to fabricate nanomaterials termed <u>top-down approach</u> and <u>bottom-up approach</u>





- Some of the physical and chemical characteristics exhibited by matter may experience dramatic <u>changes</u> as particle size approaches atomic dimensions. <u>For example</u>, materials that are opaque in the macroscopic domain may become transparent on the nanoscale.

MODERN MATERIALS' NEEDS

In spite of the tremendous progress that has been made in the discipline of materials science and engineering within the past few years, technological challenges remain, including the development of even more sophisticated and specialized materials, as well as consideration of the environmental impact of materials production.

For example, The hydrogen fuel cell is another very attractive and feasible energy-conversion technology that has the advantage of being nonpolluting.

Thank you for your attention

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